POWER CONSUMPTION OF MACHINE TOOLS

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POWER CONSUMPTION OF MACHINE TOOLS

A THESIS

PRESENTED BY

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POWER CONSUMPTION OF MACHINE TOOLS.

PREFACE

The object of this report is to study and obtain the power consumption of machine tools for the purpose of embodying this item of expense into the calculation of the hourly machine rate of various machines; and to arrive at some conclusion whereby the proper size of motor for individually driven machines may be chosen.

The report is presented in two sections and an appendix. The first section consists of the introduction and two parts. It is the preliminary report, and it tabulates the various values to be obtained and the reason for the need of these values. It also consists of an outline of "The Art of Cutting Metals", by Frederick W. Taylor. The conditions of this article are needed for scientific analysis, and are therefore presented in brief form. The

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second section consists of the results obtained, arranged in definite form, the plotted curves, and the conclusions drawn. The appendix relates to the miscellaneous incidents observed in the experimental work, and contains the bibliography used in this presentation.

All of the power consumption tests were carried out in the machine shop of the Link-Belt Company, Chicago, with graphic wattmeter. This fact limits the scope of this thesis to machines driven by direct current motors, and the data to apparatus and to actual working conditions as found in this shop.

Appreciation

The authors wish to take this oportunity in expressing their appreciation for the assistance given them by the following: Professor E.H. Freeman, Professor J.E. Snow, Mr. C.I. Drake, Mr. W.V. Lindblom, and to especially thank Mr. Gayman of the Link-Belt Company for allowing us the full freedom of the machine shop of that company.

J.L.B.
A.C.K.
L.H.R.

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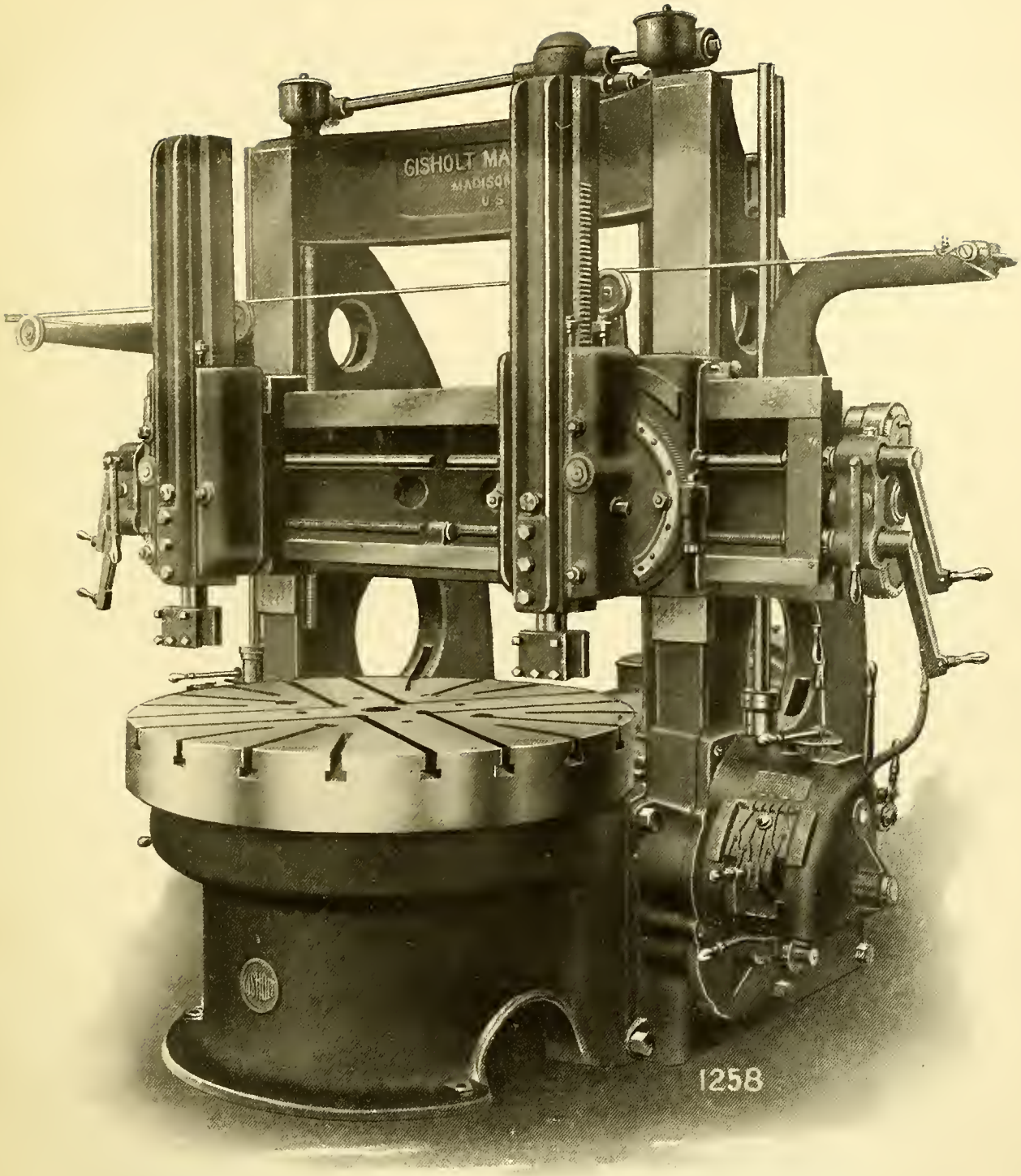

GISHOLT 52-INCH VERTICAL BORING AND TURNING MILL

Belt Driven

Description and general dimensions are on next sheet

SECTION ONE

POWER CONSUMPTION OF MACHINE TOOLS.

SECTION ONE

Introduction

The modern manufacturer is giving more and more attention to an accurate factory cost system. For, with it, the distribution of profit and loss is obtained by itemizing and grouping the various factors involved in such a manner as to show at any time where improvement is possible.

Whatever the nature of the business, the item of power cost is sufficiently important to be a determining factor in the total cost of a finished product and for this reason it should be given as much attention as the accounting of any other manufacturing expense.

However, this power cost has not been scientifically ascertained.

It is in the hope that the possibilities of further economy and of accurate cost

accounting in power consumption may be more fully realized that this study of the power consumption of machine tools is made.

In this report, the individually driven machines in the machine shop of the Link-Belt Company shall be considered. This Company uses the Taylor System of planning, and an accurat e cost system. The following brief outline on costs does not apply strictly to the above mentioned Company, but it is intended as a general outline for obtaining the cost of a product.

We may obtain the cost of a product by adding the cost of

(1) Materials

(2) Labor used directly in production

(3) Indirect expenses
    (a) Administrative and selling
    (b) Factory overhead.

Indirect expenses are sometimes not subdivided, but the tendancy in more accurate

cost analysis is to exclude the purely administrative and selling expenses from the factory overhead as applied by scientific machine rates.

The administrative expense may be classified as follows:

Accounting
Cost Department
Purchasing
Stores
Liability insurance for office force
Heat and light for office
Building maintenance for office
Patent expense
Legal expense
Office supplies
Collection and exchange
Telephone and telegraph
Bad debts
Discount allowed
Insurance and taxes on equipment
General office charge.

The selling expense may be classified as follows:

General Sales Department
Contract and Estimating
Order Department
Shipping Department
Billing
Stenography and filing

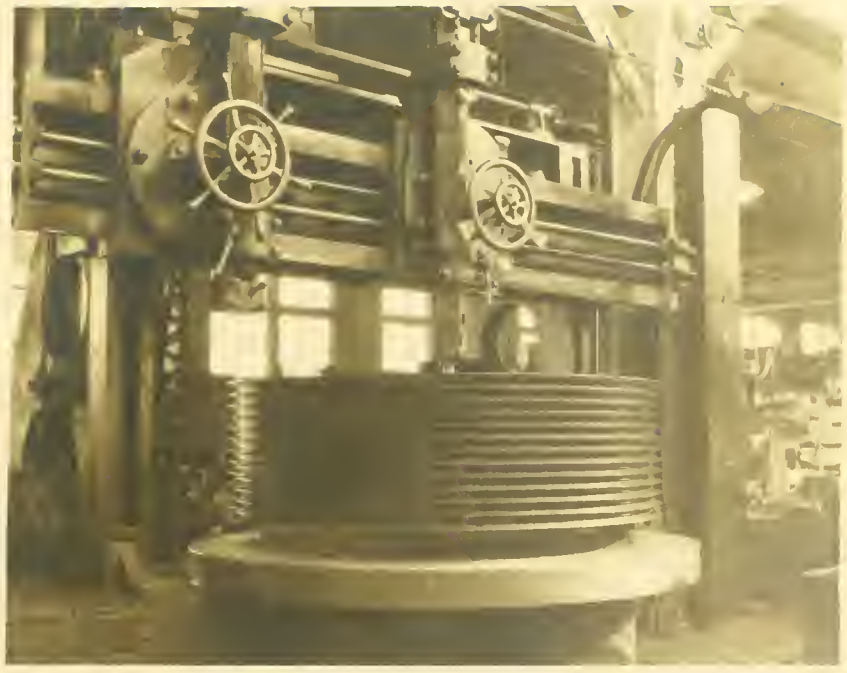

Fig. 1 Cable Drum on a 96-in. King Vertical Boring Mill.

Liability insurance on sales force
Light and heat for sales force
Diplomatic allowances
Building maintenance for sales office
Insurance and taxes on sales equipment
Branch office expenses.

The factory overhead expense may be distributed on the basis of machine rates. The hourly machine rate consists of the calculation of the following:

(1) Machine cost

(2) Cost of floor space

(3) Non-productive supervising labor

(4) Power cost

(5) Miscellaneous expenses.

(1) The machine cost will consist of the following:

(a) Interest on investment in machinery

(b) Amortization fund

(c) Cost of repairs and maintenance

(d) Insurance and taxes

(e) Miscellaneous supplies.

The interest on the investment is a direct calculation of the rate of interest times the first cost. The first cost includes the sum of all the expenditures made for the purchase and installation of the machinery. The amortization fund provides for the depreciation, and it supplies the amount for the replacement of the machine at the end of the estimated life. This replacement amount will consist of the first cost of a new machine minus the salvage value of the old machine.

(2) The cost of floor space is taken care of in a similar manner to that of the machine cost. Its items are:

(a) Interest on investment of land and buildings

(b) Depreciation of the buildings

(c) Cost of repairs and maintenance

(d) Taxes on property and insurance on buildings.

In the calculation of the amount of floor space, consideration should be given to the amount of space necessary for the workman and for the average amount of material to be machined that is usually near the machine.

(3) The amount of supervising labor depends on the number of men rather than the number of machines. However, the proper proportion of charge to supervising labor for each machine may be determined.

The power cost may be taken into account by a more or less elaborate estimate of power consumed by each machine, or according to the actual power requirements as determined by measurements. Each department may have separate metered power circuits in order that it may share the power proportion of the power bill.

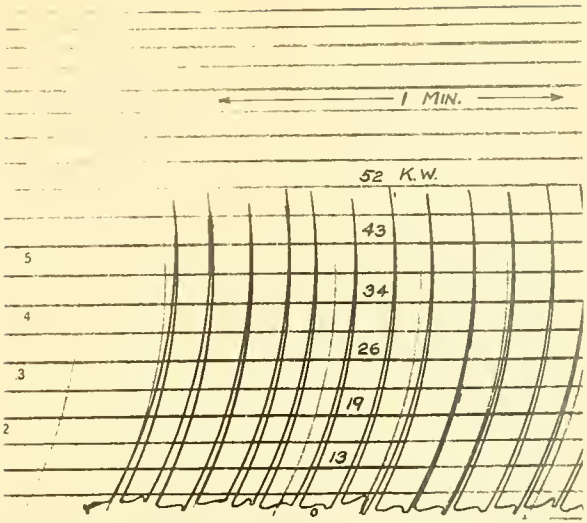

Fig. 2 Power Curve from Graphic Meter and 200 Ampere Shunt of a 60-in.x72-in.x14-ft. Pond Planer.

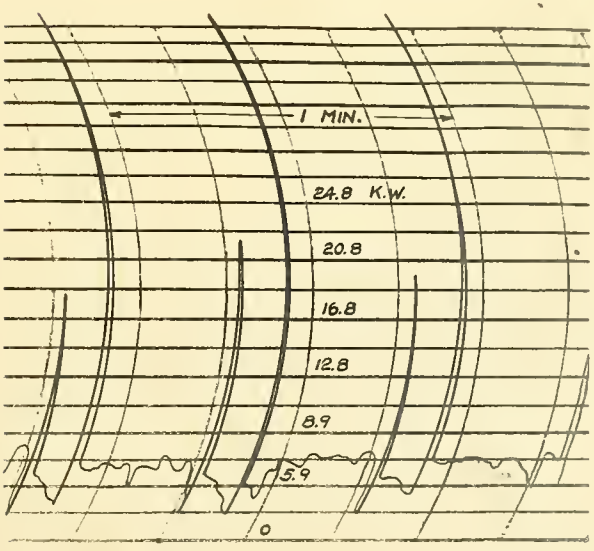

Fig. 3 Power curve from Graphic Meter and 100 Ampere Shunt on same Casting with stroke increased.

POWER CONSUMPTION OF MACHINE TOOLS.

If the power is bought from a central station, the charge may be made by any one of a large number of electric rates. In many cases, an isolated plant is installed to supply steam for heating and other purposes as well as for power, and only the proper proportion of plant cost should be charged to power.

(4) The cost of power may be divided into two general heads: Cost of production, and fixed charges.

The cost of production expenses are generally:

(1) Fuel, including freight, hauling and unloading into coal bunkers

(2) Ashes removal

(3) Water, and boiler compound

(4) Lubricants and miscellaneous prime mover and electrical supplies

(5) Labor of all power plant hands, including pro-rated wages of timekeeper, watchman, clerks,

and supervision

(6) Material and labor for repairs and maintenance

(7) Miscellaneous expenses.

The fixed charges are:

(1) Interest on the investment

(2) Amortization fund

(3) Insurance and taxes

(4) Floor space

(5) Obsolescence

(6) Reserve power generating capacity.

Obsolescence may be considered by decreasing the calculated useful life of the plant. It may be offset, in some cases, by improvements which should, to be economic, decrease the cost of production. The improvements would increase the interest and depreciation charge.

Continuity of service is important in most power applications, and is generally assured

by central stations. If reserved units have been installed in an isolated plant, continuity of service is made more certain, and, provided there is no other breakdown of its system from the coal pile to the service, probable loss due to failure of power at the receiving end is averted. The increase in interest and depreciation charge may be justified by the improved service.

POWER CONSUMPTION OF MACHINE TOOLS.

Part One.

Power Requirements of Metal-Cutting Machines.

The actual average power requirements of an individually driven machine may be determined from average work with a graphic meter to determine the power cost in the machine rate. It may be desired to calculate the power cost in the machine rate of a proposed machine which has not been installed. The cubic inches of metal removed per minute can be calculated for both average and maximum cuts from the area of the cut and the cutting speed. The power required to drive the machine idle may be secured from the makers. If a relation can be established between the amount of metal removed per unit time and the horsepower, the power consumed would be this constant for the quality of metal to be machined multiplied by the cubic inches of metal removed per minute, provided this was the basis

Fig. 4 Crusher Roll on a 36-in. Lodge and Shipley Engine Lathe.

of the constant, added to the friction load of the machine. There is considerable lack of agreement among authorities on such a constant. An attempt will be made experimentally to determine such a constant under the conditions of operation as found in the machine shop under consideration.

For direct current, there are three items to be considered in determining the size of motor. These items are the horsepower, the speed and the voltage.

The voltage should be the same as the line to which the motor is to be connected.

To determine the speed, it is necessary to know whether the motor whll be directly or indirectly coupled. The maximum and the minimum speeds of the motor may then be determined. It is frequently better to limit the range of speeds and have closer speed adjustment than to have a

liberal speed range with a larger speed gap between steps.

The proper speed-torque characteristic for a motor depends upon the machine to be driven. A motor may have:

(a) Constant speed characteristic

(b) Compound speed characteristic

(c) Variable speed characteristic

(d) Adjustable speed characteristic

(a) Constant speed motors are used where constant speed is desired under all conditions of load. The shunt motor comes under this class.

(b) The speed variation of a motor of the compound type with a change in load is less than that of a variable speed motor and greater than that of a constant speed motor; and its maximum starting torque is also less than that of a variable speed motor and greater than that

of a constant speed motor. This type is applicable to work having fairly heavy starting torque, or frequent starting and reversing, and for work requiring only fairly constant speed. The compound wound motor comes under this class.

(c) Variable speed motors give heavy starting torque and the speed is dependent upon the load. They are never run without load. The series wound motor comes under this class.

(d) An adjustable-speed motor may have its speed adjusted over a wide range, and the speed will remain practically as adjusted for all changes of torque within its capacity. In this type of motor, the speed varies inversely and the torque directly with the field strength, and this product, for the same armature current will be constant. By proper adjustment of the speed, the motor may be run at a constant power output for either heavy or light work. Shunt

wound motors with commutating poles and motors in which the magnetic flux is varied by changing the reluctance of the magnetic circuit come under this class.

The choice of the correct size of motor for a particular machine is of great importance. The conditions under which the motor will operate determines whether the motor will be open, semi-enclosed, or enclosed, and this affects the capacity of the motor. The makers of machine shop machinery are usually relied upon to specify the motor for the machine. Actual tests show that many manufacturers specify motors which are not of the most economic size, and the general tendency is towards motors that are too large. This is probably due to the fact that the improvements in commutation with the introduction of interpole motors with a consequent increase in capacity have not been fully realized. Commutating

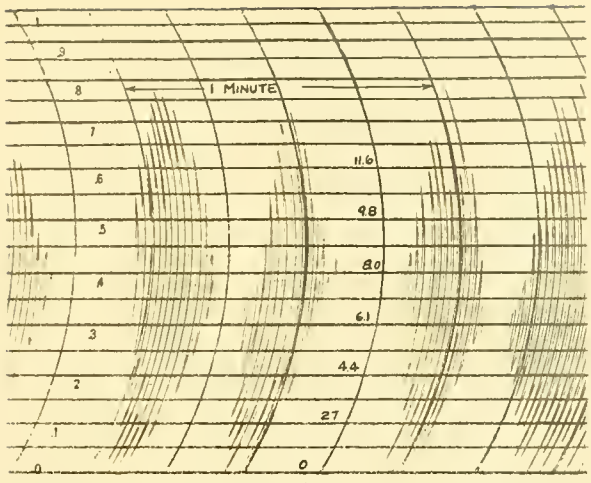

Fig. 5 Power Curve of Graphic Wattmeter and 50 Ampere shunt on a Norton Grinding Machine.

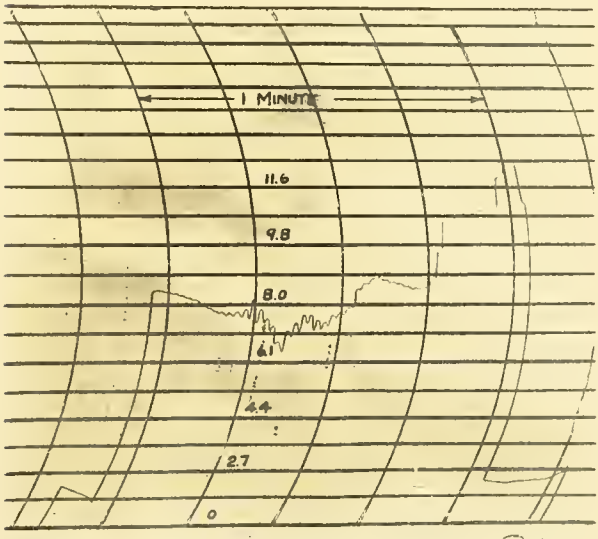

Fig. 6 Same conditions as in Fig. 5 with a more regular and better centered casting.

pole, direct current motors will stand 100% to 125% overload without sparking.

The proper size of motor should be obtained from the root-mean-square value of the power for an entire cycle which represents average conditions of service, provided its overload capacity will take care of the maximum loads. This value may be calculated from the curves of the graphic meter, or it may be obtained experimentally, as will be shown later. The heating of a motor under intermittent load will be the same as if the motor were run constantly at a load equal to the square root of the mean square load. All good motors have a 25% overload capacity for a period of at least two hours; 60% for three minutes; and 100% for ten seconds. Since a motor is run idle and on finishing cuts a great deal, it is desirable to have one which will be efficient during this

time, and which will also withstand the peak loads without injury. A study of motor efficiency curves shows the advantage of running the motor near its rated capacity.

By actual measurement of the power consumption, or of the heating with a test motor, the determination of the proper size of motor may be made; or the tests may be run to determine whether or not the machine under test is properly motored.

If the root-mean-square value of the current is determined by use of the principle of the thermos bottle, the most economic size of motor may be determined for intermittent loads of large values of fluctuation.

If a graphic meter is used, various improvements from the standpoint of power consumption may be suggested from the nature of the curves. The main features that may be

obtained are:

(a) Actual power consumed

(b) Time to complete certain cuts, which will check time and motion studies

(c) Data for determining hourly machine rate

(d) The delays in work

(e) Length of time tool is idle

(f) Value and duration of the maximum peak

(g) Unnecessary operation of the motor

(h) The most economic size and type of motor

(i) Relation between the amount of metal removed and the horse-power.

POWER CONSUMPTION OF MACHINE TOOLS.

Part Two.

Description and Outline of Taylor's Method of Cutting Metals.

An article by Mr. F. W. Taylor on the method of cutting metals, presented to the American Society of Mechanical Engineers, states that there are three factors that must be determined by every machinist operating a metal-cutting machine on every metal cutting operation. These factors consist of: the tool to be used, the cutting speed, and the feed.

An investigation which lasted twenty-six years with the sole purpose of determining the above factors under all varying conditions of machine shop practice was carried on by Mr. Taylor and his associates. In this extensive work, Mr. Taylor confined himself exclusively to an attempted solution of the problem as affects roughing work; finished cuts not being

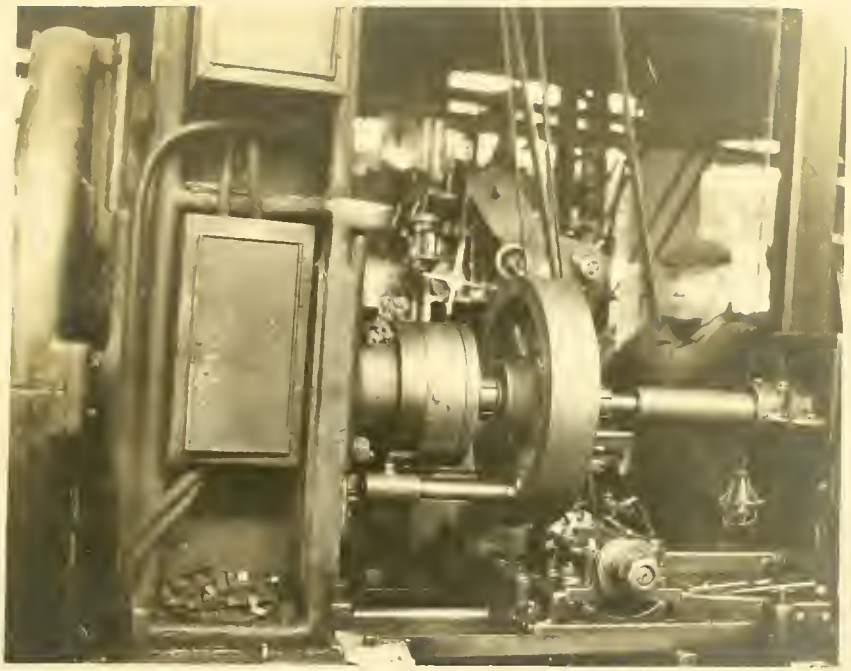

Fig. 7 Gear in an 84-in. Gould & Eberhart Gear Cutter.

dealt with. Below, a brief outline will be made of the fundamental laws and principles discovered and formulated by Mr. Taylor.

The whole subject may be easily divided into two parts, namely, all matter dealing with the choice of the tool and all substances concerning the cutting speed and feed. In the first section there will be given a brief discussion of the elements affecting the selection of the tool; and in the second section the elements affecting the cutting speed and feed will be investigated.

(1) The ideal selection of the tool is such that the tool removes the metal in the shortest time with the minimum cost in power and grinding and yet leaves a true and sufficiently smooth surface.

By changing the chemical composition of a tool a great gain can be had in cutting

metals. A greater proportional gain can be made in cutting soft metals through the use of tools made from self-hardening steels than in cutting hard metals. The gain made by the use of self-hardening tools over tempered tools in cutting soft cast iron is almost ninety percent, whereas the gain in cutting hard cast iron is only about forty-five percent.

The hardness and endurance of tools, as well as their cutting speeds, are materially improved when a small quantity of vanadium is added to the tool steel to be used for making modern high speed chromium-tungsten tools which are heated near to their melting point.

One of the results of the investigation was the discovery of the Taylor-White process of treating tools by heating them almost to

the melting point, or in other words, the introduction of the modern high speed tools. The advantages of the high speed tool, whose chemical composition is one half of one percent, or more, of chromium in combination with one percent, or more, of tungsten, is that it requires less knowledge and skill in its treatment than is demanded by carbon tools, and that it may be used satisfactorily with greater speeds. In extreme cases a speed seven times that used with carbon steel may be possible with a high speed tool.

As regards the contour of the cutting edge of the tool it may be said that a round nosed tool can be run at a much higher cutting speed and therefore turn out much more work than the old-fashioned diamond-pointed tool. The object in having the cutting edge of a roughing tool curved, as that part of the

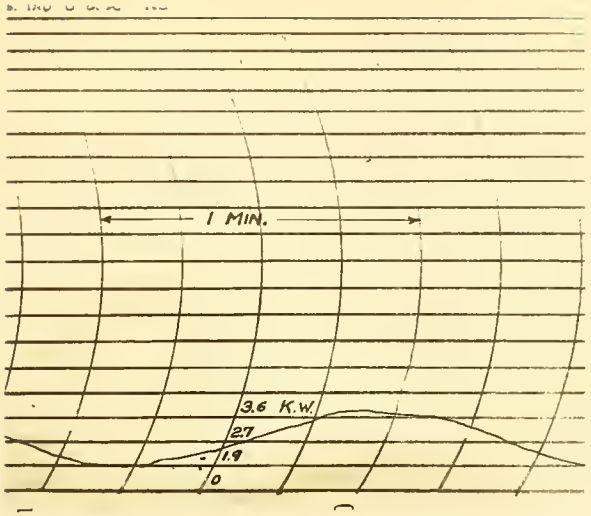

Fig. 8 Power Curve from Graphic Wattmeter and 50 Ampere shunt of cast iron gear in an 84-in. Gould & Eberhart Gear Cutter.

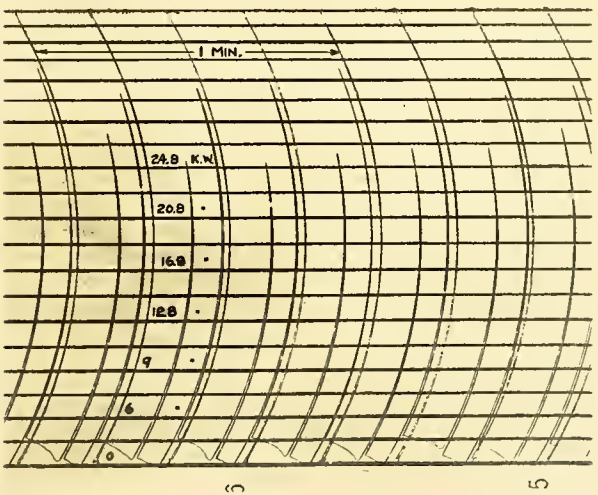

Fig. 9 Power Curve from Graphic Wattmeter and 100 Ampere shunt of a Side Planer with Automatic Reversing Mechanism.

cutting edge which does the finishing is approached, is to thin down the shaving at this point to such an extent as will insure the finishing part of the tool remaining sharp and uninjured, even tho the main portion of the cutting edge may have been ruined thru overheating or from some other cause.

There are several considerations which affect the choice of clearance angles on machine tools. The larger the clearance angle, the greater will be the ease with which the tool can be fed to its work. Every increase in the clearance angle takes an equal amount from the lip angle, and therefore subjects the tool to a greater tendency to crumble away at the cutting edge. The tool travels in a helical path around the work which it is cutting in the lathe, and the angle of this path in the case of the coarser feeds, taken upon small diameters of

work, becomes of distinctly appreciable size. The clearance angle adopted should be sufficiently large to avoid all possibilty from this source of rubbing the flank of the tool against the spiral flank of the forging.

The most important consideration in choosing the lip angle is to make it sufficiently blunt to avoid danger of crumbling at the cutting edge. The pressure upon the tool is another consideration in selecting the lip angle. The lip angle ranges between 54 and 90 degrees depending upon the quality of metal to be cut.

(2) The cutting speed of a tool depends upon the following elements:

(A) The quality of metal that is to be cut, that is, the hardness and structure of the metal.

(B) The chemical composition of the steel from which the tool is made and the heat treatment of the tool.

(C) The thickness of the shaving.

(D) The shape or contour of the cutting edge of the tool.

(E) Whether a copius stream of water or other cooling solution is used.

(F) The feed and the depth of the cut.

(G) The duration of the cut.

(H) The lip and clearance angles of the tool.

(I) The elasticity of the work and the tool on account of the producing of chatter.

(A) Although a large amount of study has been made upon the effect of the quality of the metal being cut on the cutting speed, yet there has been less success obtained in reducing this subject to a scientific basis than any other element affecting the cutting speed.

The best guide to hardness as it affects the cutting speeds lies in the physical properties of steel as indicated by the tensile

strength and percentage of stretch and the contraction of area of standard test bars cut from the body of the forging. The following empirical formula is a guide to the cutting speed of steel of good quality when the physical properties of the forging are known, as represented by a standard test bar 2 in. x $2\frac{1}{2}$ in., cut from the body of the forging and broken in a test machine.

$$V = \frac{125(1-215/(15+E)^{2})}{\sqrt{(S/10,000)-3}\ -0.9}$$

where V = standard cutting speed

S = tensile strength in pounds per square inch.

E = percentage of elongation of the specimen.

At both extremely high and low speeds this formula gives erroneous results.

It is much more difficult to predict the

Fig. 10 60-in. Gisholt Horizontal Boring Machine

correct cutting speed for cast iron than for steel, and as yet no reliable method for doing this has been discovered. It may be said, however, that the cutting speed becomes less the smaller the amount of silicon contained in the casting.

The quality of red-hardness in tools plays a much smaller part in cutting cast iron than in cutting steel; therefore with high speed tools there is much less percentage of gain in cutting cast iron than in cutting steel.

(B) It has been previously pointed out that a material increase in speed may be realized by using a tool having certain chemical composition and heat treatment. In cutting steel with high speed tools, satisfactory results are obtained with speeds seven times that used with carbon steel tools. Inasmuch as this subject has been previously discussed, no more

will be said of this element.

(C) The thickness of the chip or layer of metal removed has a greater effect upon the cutting speed than any other element. The realization of the above fact led to the use of coarse feeds and higher speeds with broad nosed tools, instead of coarse feeds and low speeds.

An experiment in the measurement of power required to feed a round nosed tool with varying depths of cut and thickness of shaving when cutting steel showed that a very dull tool requires as much pressure to feed it as to drive the cut. This discovery led to a change in the design of the steel cutting machines. Machines were then designed to have feeding power equal to their driving power.

Experiments with straight edge tools upon the effect of varying thickness of the shaving, a heavy stream of water being used to cool

the tool when a shaving of exactly one inch long was removed resulted in the derivation of the following emperical formula:

$$V = \frac{1.54}{t^{2/3}}$$

in which,

V = cutting speed in feet per minute for a twenty minute cut, and

t = thickness of shaving in inches.

Experimenting upon the same tool and noting the effect of varying the length of shaving, removing in all cases a shaving 0.03 inches thick with water as a lubricant, gave rise to the following formula:

$$V = \frac{12.22}{L^{7/32}}$$

in which,

V = cutting speed in feet per minute for a twenty minute cut, and

POWER CONSUMPTION OF MACHINE TOOLS.

L = length of shaving in inches.

A change in speed produces a change in thickness of the chip, and it is the actual thickness of the chip as it crosses the line of the cutting edge of the tool which produces a change in cutting speed; the thicker the chip the slower the cutting speed. The actual thickness of the chip is dependent not only upon the coarseness of the feed but also upon the shape of the cutting edge of the tool and upon the position of the tool in the tool post.

(D) Another element that influences the cutting speed is the contour of the cutting edge of the tool, chiefly because of the effect which it has on the thickness of the shaving. A tool with a cutting edge having a curved outline produces a chip varying in thickness at all points. The chip removed by a tool with a large curve for cutting edge is much thinner than that removed by

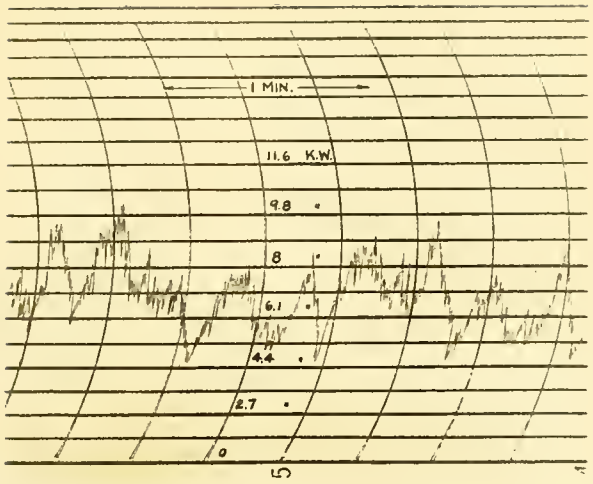

Fig. 11 Power Curve from Graphic Wattmeter and 50 Ampere shunt of a King Vertical Boring Mill. The roughing cut causes a vibratory motion of the motor.

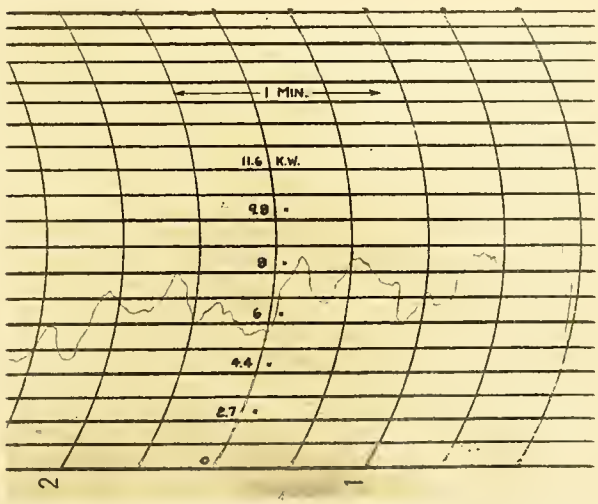

Fig. 12 Same conditions as Fig. 11 having an irregular cut, but eliminating the vibratory motion.

a tool with a small curve for a cutting edge. Therefore since the tool with a large curve for cutting edge thins down the shaving, the cutting speed may be increased when this tool is used.

(E) Cooling the nose of the cutting tool by throwing a heavy stream of water or other liquid directly on the chip at the point where it is being removed by the tool from the forging enables the machinist to increase the cutting speed materially. For the most economical results a heavy stream of water (3 gallons per minute for a 2 in. x $2\frac{1}{2}$ in. tool) should be thrown upon the chip at the point where it is being removed from the forging by the tool for the most efficient results. Water of any quantity thrown on some other part of the tool or forging will give less efficient results.

The gain in cutting speed by the use of

water on the tool is practically the same for all qualities of steel. The percentage of gain in cutting speed through the use of water on the tool is the same whether thin or thick chips are being removed by the tool.

In cutting cast iron with modern high speed tools a gain in cutting speed of 16% can be made by throwing a heavy stream of water on the chip.

In cutting steel, the better the quality of the tool steel, the greater the percentage of gain through the use of a heavy stream of water thrown directly upon the chip. The gain for the different types of tools in cutting steel are as follows:

(a) Modern high speed tools--------40%

(b) Old style self hardening tools-33%

(c) Carbon tempered tools----------25%

(F) The effect of feed and depth of cut

on the cutting speed is very marked. With any given depth of cut metal can be removed faster by using the combination of a coarse feed with its accompanying low speed than by using a fine feed with its accompanying higher speed. The cutting speed is affected more by the thickness of the shaving than by the depth of cut. A change in the thickness of the shaving has about three times as much effect upon the cutting speed as a proportional change in the depth of cut.

With the best modern high speed tools, varying the feed and depth of cut causes the cutting speed to vary in practically the same ratio whether soft or hard metals are being cut.

(G) The most important practical decision to be made after studying the laws of the effect of the duration of cut upon the cutting speed is: what is the most economical length of time for running each sized tool before grinding it?

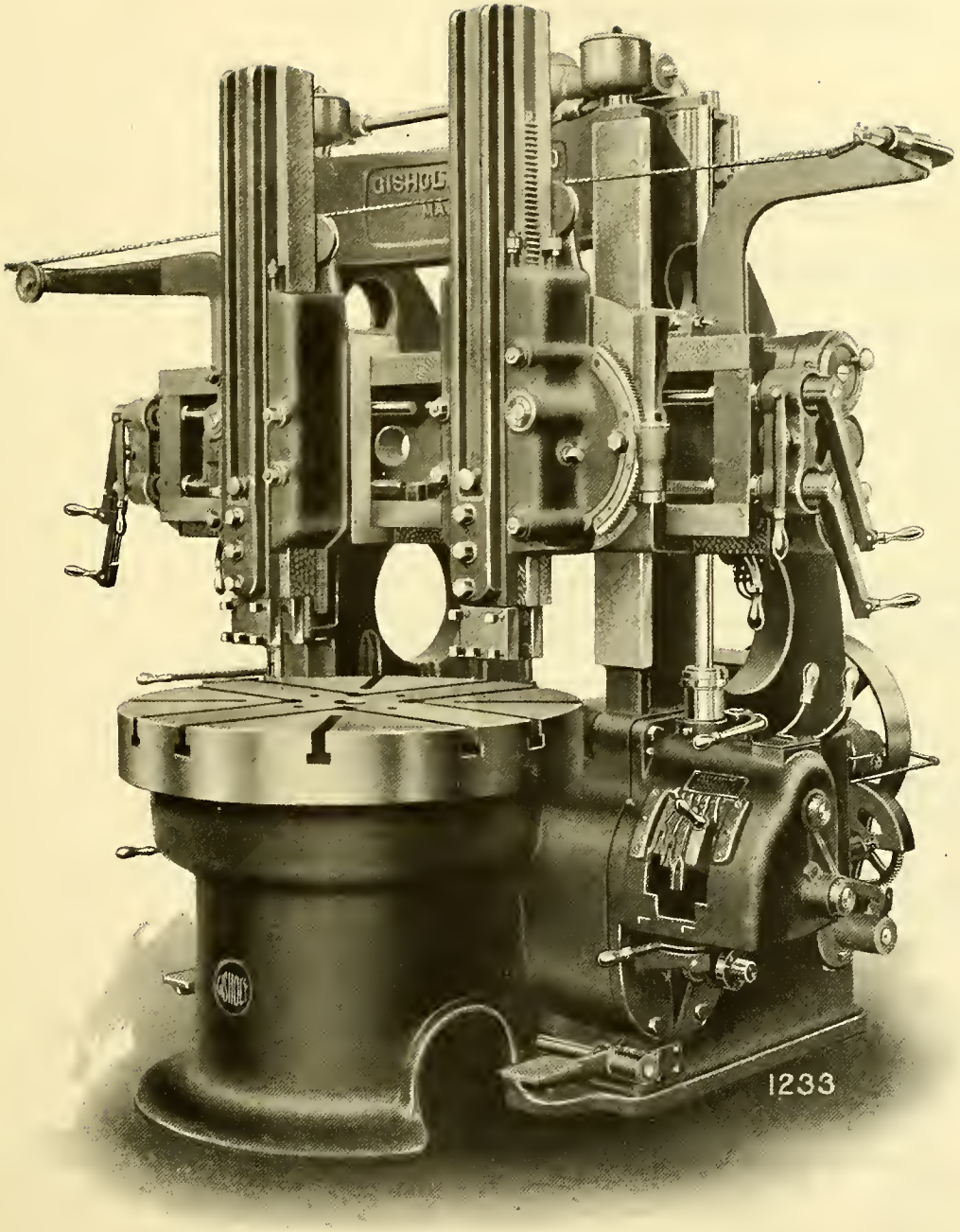

Fig. 13

GISHOLT 42-INCH VERTICAL BORING AND TURNING MILL

Belt Driven

Description and general dimensions are on next sheet

POWER CONSUMPTION OF MACHINE TOOLS.

On the other hand we have the fact that the more often we are willing to grind the tool, the higher the cutting speed at which the tool may be run. But there are four opposing considerations, all of which lead to a greater expense the more frequently the tool is ground. These items of expense are as follows:

(1) The time required to remove the worn out tool; get another sharp tool; set and clamp it in the tool post; and again start the roughing cut.

(2) The time of the tool grinder and grinding machine and the wear on the emery wheel each time the tool is ground.

(3) The cost of smith's and helper's wages, fire, blast, etc., in the smith shop for dressing the tool.

(4) The cost of the tool steel each time the tool is dressed.

The longer the tool is called upon to work continously under pressure of a shaving, the slower must be the cutting speed. The effect of the duration of the cut upon the cutting

speed is expressed in the equations given below. If we let,

V = speed of tool in feet per minute

T = length of time tool must last without grinding in minutes,

then

$$V = \frac{90}{T^{1/8}}$$

Experiments with a 7/8 in. x 1 3/8 in. carbon tempered round nosed tool upon the effect of cutting speed with the variation of the time that the tool is under cut gave rise to the following equation;

$$V = \frac{11.3}{F^{0.65} T^{1/5}}$$

where V = cutting speed in feet per minute

T = time tool is under cut in minutes

F = feed in inches.

The above equations are only true for steel forg-

ings. The same relation exists between the duration of cut and cutting speed for steels of different degrees of hardness.

(H) The effect for good or evil of the lip and clearance angles of tools upon the cutting speed is much less than is ordinarily attributed to them, but a brief discussion of them will not be out of place at this time. By the proper choice of lip and clearance angles the cutting speed may be materially improved.

In cutting cast iron, higher speeds may be realized by use of tools with blunt cutting edges. This is due to the fact that the blunt angle tool has a large section of metal for carrying away the heat due to friction and the wear of the tool is less affected due to the blunt cutting edge.

In cutting soft steel we have exactly the reverse effect as that of cast iron. This is

due to the fact that the pressure of the chip comes at a considerable distance from the cutting edge.

(I) Chatter is one of the most delicate problems, and in the case of castings and forgings of different shapes probaly no rule or formula can be devised which will accurately guide the machinist in taking the maximum cuts and speeds possible without producing chatter.

Chatter may be caused by the method of driving the work, by the nature of the work, by the cutting tools, or by the design of the machine. Too small lathe dogs or clamps or an imperfect bearing at the points at which the clamps are driven by the force plates produce vibration.

It is economical to use a steady rest in turning any piece of cylindrical work whose length is twelve times its diameter, or more.

To avoid chatter, tools should have cutting

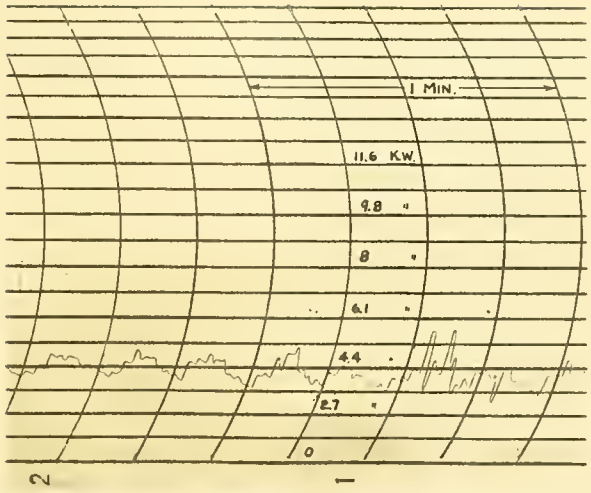

Fig. 13a Power Curve from Graphic Wattmeter and 50 Ampere shunt of King Vertical Boring Mill cutting on gear wheel. Notice uniformity of cut as tool approaches center.

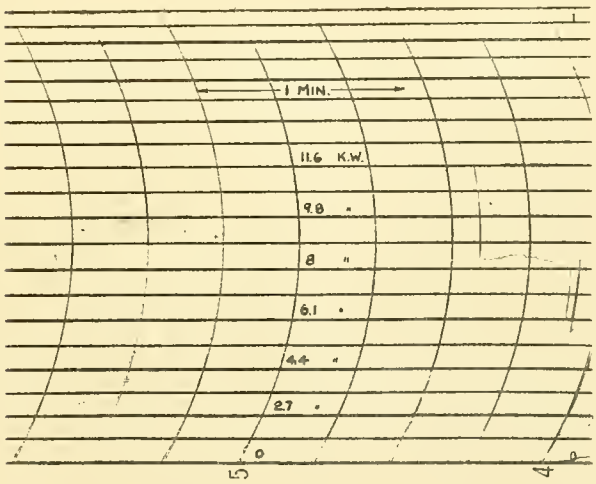

Fig. 14 Power Curve from Graphic wattmeter and 50 Ampere shunt of King Vertical Boring Mill with a facing cut.

edges with curved outlines and the radius of curvature of the cutting edge should be relatively small compared with the work to be operated on. Chatter can be avoided even in tools with straight cutting edges by using two or more tools at the same time. The bottom of the tool should have a true solid bearing and the body should be greater in depth than width.

Chatter in the machine may be caused by the following:

(1) Badly made or badly fitted gears.

(2) Loose fitting in the bearings.

(3) Shafts too small in diameter or too great in length.

(4) Machine parts not being massive enough to absorb vibrations due to high speeds.

Chatter of the tool necessitates cutting speeds from ten to fifteen percent lower than those taken without chatter whether tools are run with or without cooling water.

POWER CONSUMPTION OF MACHINE TOOLS.

The greatest value of the experiments and the mathematical work carried on by Mr. Taylor is the developement of a slide rule which involves the mathematical expression of the exact effect upon the cutting speed of such elements as the cutting edge of the tool, the thickness of the shaving, the depth of cut, the quality of the metal being cut and the duration of the cut. This work enables one to fix a daily task for each workman who is running a metal cutting machine, and to pay him a bonus for rapid work, as the time that should be consumed can be calculated.

The gain from these slide rules is greater than all of the other improvements put together because it makes it possible to take the control of the machine shop out of the hands of the various workmen and place it completely in the hands of the management.

POWER CONSUMPTION OF MACHINE TOOLS.

Part Three.

Description of the Data Required in the Determination of the Power Consumption.

The data required in the determination of the power consumption must be complete and must include all of the details that would tend to make any variation in this power consumption.

The following is a description of the data required from the machine tool work, and a discussion of the principles and the losses of the motor used in driving the machine.

METAL CUTTING MACHINE

There are two distinct types of machine tool work on metal cutting machines. These types of machines are:

(1) When the material is in motion,

(2) When the material is stationary.

The first case includes the majority of the machines used in this work, their type being

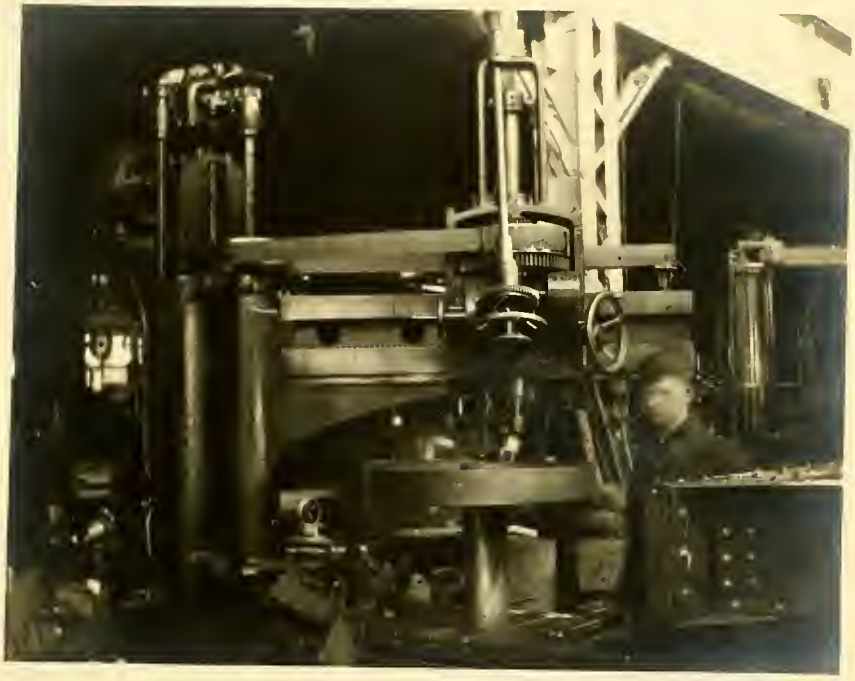

Fig. 15 6-ft. American Radial Drill Press.

POWER CONSUMPTION OF MACHINE TOOLS.

such as:

Vertical boring mills
Lathes
Planers,
Milling machines.

The second class consists of:

Horizontal boring mills
Drills
Gear cutters
Slotters,
Shapers.

(1) When the material is in motion the main items to be considered are, the speed of the material to be cut, and the speed of the tool. In the lathes and vertical boring mills the motion of the material is that of rotation, whereas in the milling machines and planers it is that of reversing translation. But the final form that is to be considered in both cases is the speed at which the material is passing the tool at the point of cutting, or, in other words, the actual cutting speed.

POWER CONSUMPTION OF MACHINE TOOLS.

The cutting speed of the planers and of the milling machines will be constant thruout the operation of a cut providing the gear ratio or the speed of the motor is not changed during this time. In the case of the lathe and the vertical boring mill for facing work, however, the torque that must be overcome in cutting will decrease as the radius of the work decreases. This will enable the rotational speed to be increased to keep the former cutting speed.

The speed of the tool will take on two aspects in this type of work. In the boring mill and lathe the speed of the tool will be the so-called feed, whereas in the milling machine the tool will be stationary with regard to a fixed position on the machine, but will have a rotational speed around its axis as the center. The planer tool does not move when it is cutting, as its feed is in operation at the time of

reversal of the bed of the planer.

(2) When the material is to be stationary the items to be considered are the different kinds of speeds of the tool as affect the cutting speed of the material.

A radial drill has a cutting speed that is determined by the size and the speed of rotation of the drill. The amount of metal cut is determined by the size of the drill, the cutting speed and the feed. Considerably more power, than is ordinarily expected, is encountered when the drill enters the material. This is due to the variable cutting speed at the cutting edge of the drill, from zero at the center to the peripheral speed of the drill at its diameter. This variable speed causes a jamming instead of a cutting action by the drill. When a lathe type tool is used on a radial drill the depth of cut is a feature on which the power consumption will

depend.

The slotters and shapers are usuall y operated by a crank and eccentric and the speed of both cutting and reversing and the feed must be determined. The feed, as in the case of planers, does not occur on the cutting stroke.

From the above it is seen that several items must be considered in determining the power consumption of machine tools and that som e direct relation may be obtained whereby the power consumption will be known if the several items are known. These factors and varying conditions may be classified as follows:

(1) Kind of machine

(2) Character of material

(3) Character and shape of tool

(4) Cutting speed of tool

(5) Feed of tool

(6) Depth of cut.

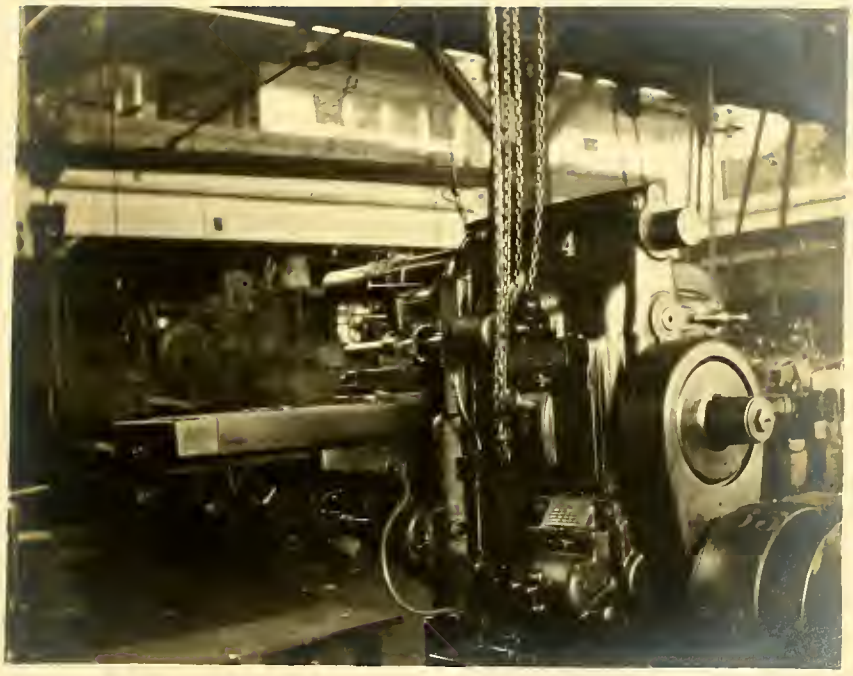

Fig. 16 Brown & Sharp Milling Machine.

POWER CONSUMPTION OF MACHINE TOOLS.

MOTOR

When a shunt motor is in operation the power consumption may be devided into several parts or losses. These losses include:

(1) Copper loss in the field and armature

(2) Iron losses of the armature and field core

(3) Friction and windage.

(1) The copper losses for any direct current circuit may be computed if the current, and the resistance thru which it flows are known. They will be equal to RI^2, where R is the resistance in ohms and I is the current in amperes. The armature copper loss as thus computed is a variable loss changing as the load on the motor changes. The field copper loss is constant for any certain position of the controller handle,

or in other words, for constant field excitation. It can be computed from the formula RI^2, or from the formula EI, the product of the current in the field and the voltage supplied at the terminals. When a rheostat is in use its resistanc e must be added to that of the field.

(2) The iron losses are losses due to hysterisis and eddy currents, and are independent of the load but may vary with the speed and the flux density of the armature. For any position of the controller handle, the flux density and speed are practically constant and therefore the iron loss can be considered constant.

(3) The friction and windage losses are also independent of the load and depend alone upon the speed of rotation of the armature. Then for any fixed position of the

controller these losses may be considered constant.

As one of the objects of this report is to obtain the actual power used by the tool in cutting the metal, it is necessary to separate the various losses of the motor. This is to be done so that the results may be applied for any case in some convienent manner.

When a machine is running idle the power consumption may be expressed in an equation as follows,

$$P_n = P_m + P_{f+w} + P_i + P_f + P_a$$

where:

P_n = Total power consumed, machine running idle

P_m = Power actually consumed in rotating machine

P_{f+w} = Friction and windage loss of the motor

P_i = Iron losses in the armature and core

P_f = Loss in field and rheostat

POWER CONSUMPTION OF MACHINE TOOLS.

P_a =Loss in armature due to heating=I^2R

The preceding equation may be summarized as follows,

$$P_n = P_F + P_V = P_F + I_n^2 R$$

if,

$P_F = P_m + P_{f+w} + P_i + P_f$ constant loss

$P_V = P_a$ =loss varying with the load

I_n =Armature current at no load

R=Resistance of the armature

Then it follows that with the machine in operation with a power consumption of P , and an armature current of I , the actual power consumed by the tool in cutting the metal will be P_U , or,

$$P_U = P_L - P_F - I_L^2 R$$

and as,

$$P_F = P_N - I_n^2 R$$

then,

$$P_U = P_L - P_n + I_n^2 R - I_L^2 R$$

POWER CONSUMPTION OF MACHINE TOOLS.

$$=P_L - P_n - R(I_L^2 - I_n^2)$$

Thus it is seen from this equation that the useful power consumed for any cut of the machine whose characteristics and losses are known ca n be easily determined.

SECTION TWO

POWER CONSUMPTION OF MACHINE TOOLS.

Part One

Outline of Method of Procedure for Testing

The machines tested were driven directly by motors of shunt type. The energy was supplied at 220 volts direct current, and as the lighting system of the plant was 110 volts, there was a potential of 110 volts between each line and ground.

The data to be obtained was the actual power by the tool in cutting the metal. As previously shown this necessitated the obtaining of the total used by the motor at no-load and at full load, and the current thru the armature at no-load and at full load.

A wattmeter was placed in the main circuit by means of an imitation fuse. This imitation fuse consisted of a burnt fuse with a lead connected to each end of the fuse and thus allowing the current coil of the wattmeter to be

in series with the main circuit. With this device a meter may be inserted in the circuit without loss of time and inconvienence to the machinist. The pressure leads of the wattmeter were placed across the main switch.

The armature circuit of the motor was opened and an ammeter of adequate range was inserted in place.

Simultaneous readings were taken of the wattmeter and ammeter. The various operating characteristics and speeds of the machine were noted at the same time and recorded on a data card.

POWER CONSUMPTION OF MACHINE TOOLS.

Part Two

Data Obtained and Constants Derived.

The data obtained and recorded below is the result of several months of testing of the various types of metal-cutting machines. As the tests were made on the actual work as it passed thru the factory, there was no definite time limit or schedule that could be followed and it will be seen from the results that some cards had one or two cuts, whereas others have as many as ten or twelve cuts.

From the preliminary testing it was quickly seen that the finishing cuts were of no consequence whatever and the difference between the power required by a finishing cut and the power at no-load was not discernable in ordinary work. For this reason the finishing cuts, although recorded, were disregarded in the calculated results.

The following is a sample data card and the sample calculations of the first cut.

POWER CONSUMPTION OF MACHINE TOOLS.

Sample Data Card

Date Jan. 4, 1917.

Machine: 96 in. Niles Boring Mill No. 28

Kind of Motor: Northern Variable Speed No. 17178

Capacity: 220 Volts; 39 Amperes; 10 H.P.; 270-1125 R.P.M.

No Load Armature Current: 30 Amperes.

Order No. 7790 Operation: Facing and Counter Boring

Description of Work and Material: Cast Steel Drum Gear

Number of Cut	1	2	3
Duration of Cut (Minutes)	44.0	4	3
Speed (R.P.M.)	2	11	16
Feed (In. per Rev.)	1/16	1/16	1/16
Depth of Cut (Inches)	3/8-3/16	1/4	1/8
Kind of Cut	Roughing	Roughing	Finishing
Kind of Tool	PRBB	PRBB	PRBB
Stock of Tool (Inches)	$\frac{3}{4}$ x $1\frac{1}{2}$	$\frac{3}{4}$ x $1\frac{1}{2}$	$\frac{3}{4}$ x $1\frac{1}{2}$
Diameter of Work (Inches)	39	7	7
Total Input (K.W.)	3.2	3.9	4.8
No Load Meter Reading (K.W.)	0.7	1.8	2.6
Armature Current (Amperes)	15	17	23

POWER CONSUMPTION OF MACHINE TOOLS.

Sample Calculations

Machine: 96 In. Niles Vertical Boring Mill

Motor: 10 H.P.; 220 Volt; 39 Ampere; 270-1125 R.P.M.

Northern Variable Speed Motor.

Work: Facing Rim and Hub of Cast Steel Drum Gear

Number of Cut:	1
Speed	2 R.P.M.
Feed	0.0625" per Rev
Depth of Cut	0.3750"-0.1875"
Distance of Tool from center	19.5"
Kind and Stock of Tool	3-PRBB
Total Input	3.2 K.W.
No Load Meter Reading	0.7 K.W.
Armature Current at Total Load	15 Amperes
Armature Current at No-Load	3 Amperes

Resistance of Motor

Full Load Efficiency of a 10 H.P. Motor=86 % *

Internal Horsepower=10/.86= 11.62 H.P.

Internal Kilowatts=11.62 x .746= 8.67 K.W.=8670 watts

*See Appendix

POWER CONSUMPTION OF MACHINE TOOLS.

Armature Copper Loss(I^2R_a)=4% of Full Load*

Then,

$$I^2R_a = \overline{39}^2 R_a = 1520\ R_a = 8670 \times 0.04 = 346 \text{ Watts}$$

$$R_a = 0.228 \text{ Ohms}$$

Power Required to Cut Metal:-

$$P_c = P_T - R_a(I^2 - I_o^2) - P_o$$

$$3200 - 0.228(15 - 3) - 700$$

2460 watts or 2.46 K.W.

Volume of Metal Removed

$$V_1 = D \times F \times S$$

$$= 0.3750 \times 0.0625 \times (2 \times 3.1416 \times 19.5 \times 2)$$

5.9 Cubic inches

$$V_2 = 0.1875 \times 0\ 0635 \times (2 \times 3.1416 \times 19,5 \times 2)$$

2.95 Cubic inches

As there are two tools cutting the total volume equals:

$V = V_1 + V_2 = 5.9 + 2.95 = 8.85$ Cubic inches per min.

Therefore the constant in this case equals:

$$C = \frac{P_c}{V} = \frac{2.46}{8.85} = 0.2780$$

*See Appendix

Table I - Machine and Motors

A- 72" King Vertical Boring Mill
15 H.P.; 220 Volt; 60 Ampere Lincoln
Electric Company Motor. R_a=0.138 Ohm

B- 72" Gisholt Vertical Boring Mill
10 H.P.; 220 Volt; 40 Ampere; 475-1186 R.P.M.
Northern Variable Speed Motor. R_a=0.228 Ohm

C- 96" Niles Vertical Boring Mill
10 H.P.; 220 Volt; 39 Ampere; 270-1125 R.P.M.
Northern Variable Speed Motor R_a=0.228 Ohm

D- 36" Lodge and Shipley Engine Lathe
10 H.P.; 220 Volt; 45 Ampere; 350-1400 R.P.M.
Northern Variable Speed Motor. R_a=0.547 Ohm

E- 48" Lodge and Shipley Engine Lathe
15 H.P.; 220 Volt; 45 Ampere; 350-1400 R.P.M.
Northern Variable Speed Motor R_a=0.25

F- 36" Lodge and Davis Engine Lathe
10 H.P.; 220 Volt; 40 Ampere; 275-1100 R.P.M.
Electric Dynamic Co. Motor R_a=0.3 Ohm

G- 24" Lodge and Shipley Engine Lathe
7.5 H.P.; 220 Volt; 30 Ampere
Northern Variable Speed Motor R_a=0.32 Ohm

H- 60" Gisholt Horizontal Boring Mill
5 H.P.; 220 Volt; 20 Ampere; 400-1600 R.P.M.
Northern Variable Speed Motor R_a=0.44 Ohm

I- 6 Ft. American Radial Drill Press
5 H.P.; 220 Volt; 20 Ampere; 275-1100 R.P.M.
Electric Dynamometer Variable Sqeed Motor R_a=1.11

J- 36" Radial Drill Press
3 H.P.; 230 Volt; 17.7 Ampere; 1100 R.P.M.
General Electric Shunt Motor R_a=0.823 Ohm

POWER CONSUMPTION OF MACHINE TOOLS.

Table II - Description of Work

1- Facing Cast Iron Drum

2- Facing Rim and Hub of a Cast Steel Drum Gear

3- Facing Cast Iron Hoist Drum Gear

4- Facing Cast Iron Crusher Roll

5- Facing and Cutting Groves in Cast Iron Hoist Drum

6- Facing Cast Steel Crusher Roll

7- Turning a Nickel Steel Shaft

8- Drilling Cast Steel

9- Boring Cast Iron Crusher Roll

10- Drilling Hammered Steel Drum Shaft

11- Boring Cast Iron Crane Cylinder

12- Facing Hub on Cast Iron Rotating Frame

13- Boring Cast Iron Rotating Frame

14- Drilling Cast Iron

15- Drilling and Boring Right Hand Side Housing

16- Drilling Cast Steel

POWER CONSUMPTION OF MACHINE TOOLS.

Table III - Stock and Size of Tool

Stock of Tool

1- 3/8" x 1½"

2- 5/8" x 1½"

3- 3/4" x 1½"

4- 7/8" x 1¾"

Size of Tool

DCRD- Cutter; Roughing; Double End for Standard Work; Cast Iron- 10 Degree Lip

PRBC- Paring Tool; Round Nose; Blunt; Left Hand; Straight

PRSF- Paring Tool; Round Nose; 30 Degree Bend; Sharp Right Hand

PRBD- Paring Tool; Round Nose; 30 Degree Bend; Right Hand

PRSC- Paring Tool Sheave; Right Hand; Bent 45 Degree; Rougher

PRBB- Paring Tool; Round Nose; Blunt Right Hand; Straight

PRBA- Paring Tool; Round Nose; Blunt Straight

PFSE- Paring Tool for Sheave; Right Hand; Straight Rougher; Bent to 45 Degree Angle

POWER CONSUMPTION OF MACHINE TOOLS.

Table IV - Notation

M-W= Machine and Motor- Description of Work

M= Kind of Material

T= Kind of Tool

L= Radius of Work in Feet

D= Depth of Cut in Inches

S= Speed in Feet per Minute

F= Feed Inches per Revolution

P = Total Power in Kilowatts

P = Power Required in Cutting Metals

V= Volume of metal Removed in Cubic Inches

C= A Constant, where VC = P

C.I.= Cast Iron

C.S.= Cast Steel

H.S.= Hammered Steel

N.S.= Nickel Steel

H.P.= Horsepower

K.W.= Kilowatts

R.P.M.=Revolutions per Minute

R = Armature Resistance in Ohms

POWER CONSUMPTION OF MACHINE TOOLS.

Table V- Vertical Boring Mills

M-W No.	M Kind	T Kind	L Feet	D Inch	S Ft.P. Min.	F In. P Rev.	P K.W.	P K.W.	V Cu.In. Min.	C
A-1	C.I.	3-PRBD	1.50	.3750	26.1	.0625	1.6	.590	7.33	.0803
A-1	C.I.	3-PRBD	1.50	.1875	26.1	.0625	1.4	.400	3.06	.1307
A-1	C.I.	3-PRSC	1.50	.2500	27.5	.0833	1.2	.200	6.88	.0291
A-1	C.I.	3-PRSC	1.50	.18750	27.5	.0833	1.6	.590	5.16	.1142
A-1	C.I.	3-PRBD	1.50	.2500	27.5	.0833	1.6	.590	6.88	.0857
A-1	C.I.	3-PRSC	1.50	.2500	27.5	.0833	1.7	.730	6.88	.1060
A-1	C.I.	3-PRBD	1.50	.1875	27.5	.0833	1.7	.730	5.16	.1415
A-1	C.I.	3-PRSC	1.50	.1250	27.5	.0833	1.2	.250	3.44	.0728
A-1	C.I.	3-PRSC	1.50	.2500	51.7	.0833	4.0	1.900	9.70	.1970
B-2	C.I.	3-PRBB	1.70	.2500	31.5	.0470	3.0	1.250	6.66	.1880
B-2	C.I.	3-PRBD	1.70	.1250	31.5	.0470				
B-2	C.I.	3-PRBB	1.70	.0937	31.5	.0470	3.2	1.450	1.66	.8730
B-2	C.I.	3-PRBC	1.70	.2500	31.5	.0470	2.9	1.200	4.44	.2700
B-2	C.I.	3-PFSE	1.70	.1250	31.5	Hand	2.6	1.000		
B-2	C.I.	3-PRBB	1.70	.1250	31.5	.0630	4.2	2.300	8.94	.2570
B-2	C.I.	3-PRBC	1.70	.2500	31.5	.0630				
B-2	C.I.	3-PRBC	1.70	.1875	31.5	.0630	4.0	1.700	4.47	.3810
B-2	C.I.	3-PRBC	1.70	.2530	31.5	.0630	3.9	1.700	9.95	.1710
B-2	C.I.	3-PRBB	1.70	.1250	31.5	.0830				
B-2	C.I.	3-PRBB	1.70	.1875	31.5	.0310	4.0	.840	2.20	.3820
C-3	C.S.	3-PRBB	1.74	.3750	22.0	.0625	3.2	2.460	9.27	.2653
C-3	C.S.	3-PRBB	1.74	.1875	22.0	.0625				
C-3	C.S.	3-PRBB	2.90	.2500	20.2	.0625	3.9	2.040	3.77	.5420
C-3	C.S.	3-PRBB	2.90	.1250	29.4	.0625	4.8	2.080	2.76	.7530

POWER CONSUMPTION OF MACHINE TOOLS.

Table VI- Engine Lathes

M-W	M	T	L	D	S	F	P	P	V	C
D-4	C.I.	4-PRSF	0.333	.3750	23.6	.0313	2.00	0.765	3.33	.2320
D-4	C.I.	4-PRSF	0.333	.3750	23.6	.0313	2.30	1.040	3.33	.3130
D-5	C.I.	4-PRBC	1.000	.1875	31.5	Hand	2.55	0.780		
D-5	C.I.	4-PRBC	1.000	.2500	31.5	.1000	4.00	2.080	9.44	.2201
D-5	C.I.	4-PRBA	1.000	.0625	31.5	.1000	4.75	2.670	2.36	1.0900
D-5	C.I.	4-PRSE	1.000	.1250	12.5	.0500	2.90	1.0100	0.93	1.0780
D-5	C.I.	4-PRBA	1.000	.0624	31.5	.1000	4.00	2.000	2.36	.8470
E-6	C.S.	4-PRSF	1.230	.1250	34.3	.0370	2.80	1.370	1.88	.7280
E-6	C.S.	4-PRSF	1.230	.2500	18.6	.0832	3.00	1.550	4.65	.3330
E-6	C.S.	4-PRSF	1.230	.2815	18.6	.0383	4.00	2.540	2.41	1.053
E-6	C.S.	4-PRSF	1.230	.2500	20.3	.0475	3.60	2.150	2.89	.7430
E-6	C.S.	4-PRSF	1.230	.2500	20.3	.0475	3.50	2.050	2.89	.7100
E-6	C.S.	4-PRSF	1.230	.2500	20.3	.0475	3.50	2.050	2.89	.7100
E-6	C.S.	4-PRSF	1.230	.2500	20.3	.0475	3.60	2.150	2.89	.7430
F-7	N.S.	4-PRSC	0.210	.1875	100.0	.0625	3.00	2.080	14.00	.1487
F-7	N.S.	4-PRSC	0.210	.2500	100.0	.0625	3.20	2.260	18.70	.1208
F-7	N.S.	4-PRSC	0.210	.1875	100.0	.0625	2.50	1.590	14.00	.1136
F-7	N.S.	4-PRSC	0.210	.0937	100.0	.0625	2.40	1.500	7.00	.2145
G-8	C.I.	1½"Drill			100 R.P.M.		3.30	2.210		

POWER CONSUMPTION OF MACHINE TOOLS.

Table VII- Horizontal Boring Machine

M-W	M	T	L	D	S	F	P	P	V	C
H-9	C.I.	2-DCRD	.185	.1875	36.8	.0286	1.60	0.489	2.37	.2065
H-9	C.I.	2-DCRD	.185	.1250	36.8	.0286	1.60	0.489	1.58	.3100
H-10	H.S.	(1-1/16")			111 R	Hand	2.50	0.967		
H-10	H.S.	Drill			111 R	Hand	2.20	0.967		
H-11	C.I.	2-PRBC	.311	.1875	39.5	.0286	2.10	1.260	2.54	.4970
H-11	C.I.	2-PRBC	.311	.1875	39.5	.0286	1.70	.8760	2.54	.3454
H-11	C.I.	2-PRBC	.311	.1250	23.1	.0286	1.50	0.588	0.99	.5850
H-11	C.I.	2-PRBC	.311	.1250	35.6	Hand	1.50	0.588		

Table VIII-Radial Drill Presses

I-12	C.I.	1-DCRD	.250	.2500	32.1	.0130	2.00	1.200	1.25	.9620
I-12	C.I.	1-DCRD	.250	.2500	41.2	.0130	1.80	1.030	1.61	.6400
I-13	C.I.	1-DCRD	.166	.2500	32.1	.0260	1.90	1.130	2.42	.4720
I-13	C.I.	1-DCRD	.166	.3125	32.1	.0140	1.70	0.947	1.68	.5620
I-13	C.I.	1-DCRD	.166	.3125	41.1	.0140	2.30	1.480	2.15	.6880
I-14	C.I.	1"Drill			230 R	1.8400	4.00	1.430	1.45	.9900
I-14	C.I.	1"Drill			200 R	1.6000	3.75	1.640	1.26	1.3070
I-15	C.S.	Drill	.166	.3280	31.9	.0080	1.60	0.471	1.00	.4710
I-15	C.S.	1-DCRD	.122	.1560	46.2	.0080	1.65	0.513	.691	.7430
I-15	C.S.	1-DCRD	.146	.2500	44.2	.0140	1.70	0.898	1.85	.4870
I-15	C.S.	1-DCRD	.156	.2500	47.6	.0140	1.60	0.813	2.00	.4065
I-15	C.S.	1-DCRD	.167	.1250	62.8	.0140	1.60	.0813	1.32	.6170
J-16	C.S.	7/8" DRILL			212 R	.2120	2.90	1.7000	1.28	1.3330

POWER CONSUMPTION OF MACHINE TOOLS.

From the above tables it is seen that various conditions will enter into the value of the constant and the results obtained could be classified in many ways. The data shows that the cutting speed and feed of the tool or the material do not enter into the results. This is true because the constant is calculated on the volume of the metal removed and this in turn depends jointly upon the cutting speed, the feed, and the depth of cut.

Therefore the variation of the constant for any type of machine will depend upon the material cue and the type of tool used. The results tabulated in the above tables are averaged according to this classification and arranged below:

Vertical Boring Mills

Cast Iron

Tool	Constant
PREB	0.1043

POWER CONSUMPTION OF MACHINE TOOLS.

Engine Lathes

Cast Iron

Tool	Constant
PRSF	0.2725
PRBC	0.2201
PRSE	1.0780

Cast Steel

PRSF	0.7168

Horizontal Boring Machine

Cast Iron

Tool	Constant
DCRD	0.2582
PRBC	0.4290

Radial Drills

Cast Iron

Tool	Constant
DCRD	0.6640
1" Drill	1.1485

Cast Steel

DCRD	0.6800
$\frac{7}{8}$" Drill	1.3333

POWER CONSUMPTION OF MACHINE TOOLS.

PRSC	0.1036
PRBB	0.4225
Cast Steel	
PRBB	0.5201

POWER CONSUMPTION OF MACHINE TOOLS.

Part Three - Description of Root-Mean-Square Meter Calibration and Results Obtained

It is seen from the power curves from the graphic wattmeter that the instantaneous values of the power vary over a wide range. As the voltage of the line can be assumed constant, the variation must be in the current taken by the motor. If from any curve the instantaneous values are noted and squared, and the square root is taken of their sum, we would have the effective value of the current or as it is commonly known, the root-mean-square current. Therefore, if we should pass this value of current thru the same resistance for the same length of time as covered by the curve, we would get the same heating energy as developed in the motor. Motors are rated on the heat energy that is to be developed by them and therefore it is essential that this factor be known.

POWER CONSUMPTION OF MACHINE TOOLS.

As it would be a long and tedious process to do this graphically, a device called a Root-Mean-Square Meter was made to give this value directly. The Root-Mean-Square Meter consists merely of a coil of resistance wire immersed in a certain amount of water. The electrical energy received by this coil will be transfered into heat energy, the amount of which, can be measured by the rise in temperature of the water.

The container for the water and coil is a vacuum bottle, as a great amount of radiation of the heat evolved would cause error in the results.

CALIBRATION

If we pass a known current thru the coil for a given length of time and measure the rise in temperature of the water during this time, a point on a calibration curve is established. The calibration curve for a number of values is shown on the following page.

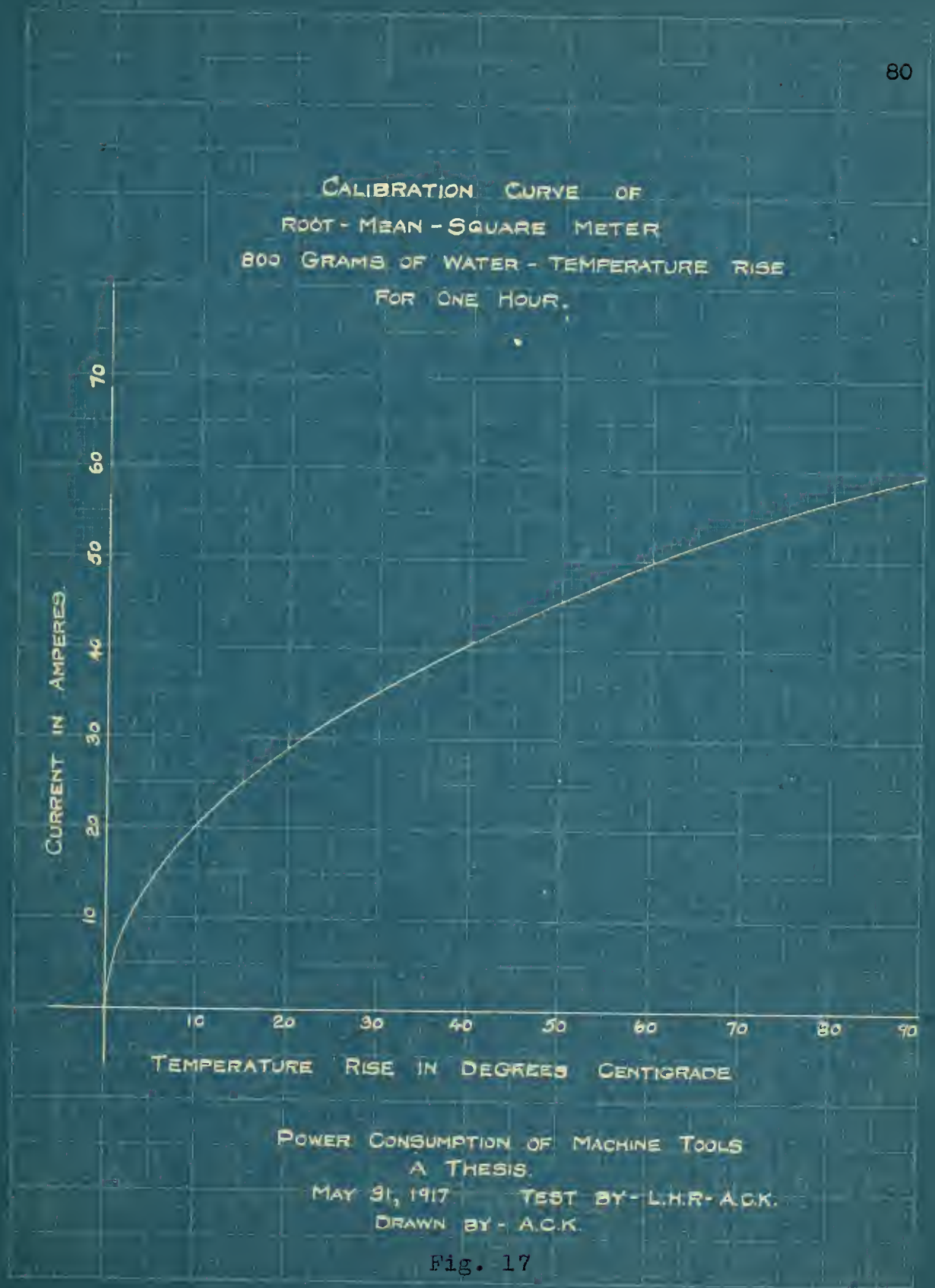
CALIBRATION CURVE OF
ROOT - MEAN - SQUARE METER
800 GRAMS OF WATER - TEMPERATURE RISE
FOR ONE HOUR.
CURRENT IN AMPERES
10
20
30
40
50
60
70
10
20
30
40
50
60
70
80
90
TEMPERATURE RISE IN DEGREES CENTIGRADE
POWER CONSUMPTION OF MACHINE TOOLS
A THESIS.
MAY 31, 1917 TEST BY - L.H.R - A.C.K.
DRAWN BY - A.C.K.

Fig. 17

POWER CONSUMPTION OF MACHINE TOOLS.

RESULTS OBTAINED

The results obtained show that the motors all have a sufficient capacity, the greatest tendency is that they are too large for the necessary work. The results obtained are tabulated as follows:

Length of Run Hours	Capacity of Motor Amperes	Root-Mean-Square Amperes
1	95	32.0
1	60	32.0
1	60	15.0
2	60	32.5
2	40	4.0
1	40	12.0
1	40	30.0
1	20	20.0

POWER CONSUMPTION OF MACHINE TOOLS.

APPENDIX

*It was found that the resistance of the motor armatures could not be measured with sufficient accuracy in the shop for calculation of the actual power consumed by the tool. As the current thru the armature at no-load was comparatively small in the majority of cases, and the resistance of the armature of shunt motors is also small, it was decided that values of the armature resistance could be assumed. Choosing the American Handbook for Electrical Engineers as a standard, the tables on page 970 were used for the efficiency of the motors and their armature copper loss as a percentage of the total input. A check could be made of these efficiency values from the rating on the name plate of the motor.

On the 60-in. x 72-in. x 14-ft. Pond Planer we found that a 40 horse power motor

required more power to reverse the bed than a 15 horse power motor. This is due to the fact that the larger motor is working lower down on its efficiency curve than the smaller motor and the constant losses are greater. Therefore it is shown that the operating cost of a motor of too great a capacity is greater than on the motor of correct size. It is also obvious that the first cost of the former will be greater.

POWER CONSUMPTION OF MACHINE TOOLS.

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